(54) Title: SYSTEM AND METHOD FOR SELECTING DATA RATES TO PROVIDE UNIFORM BIT LOADING OF SUBCARRIERS OF A MULTICARRIER COMMUNICATION CHANNEL
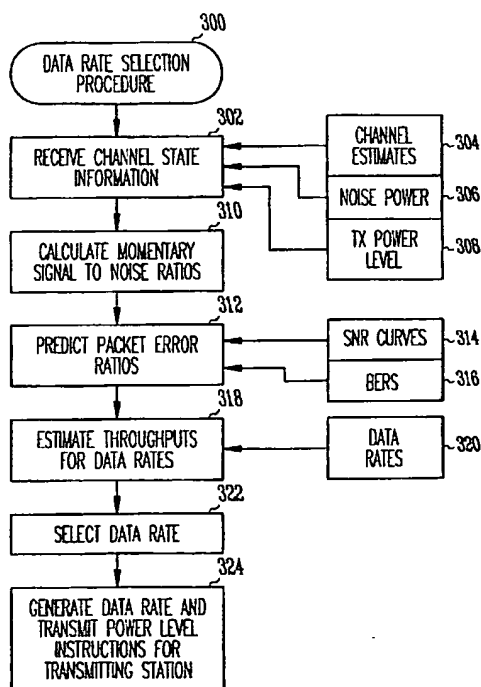
(57) Abstract: A data rate is selected for subcarriers of each frequency and spatial channel of a slowly varying frequency selective multicarrier channel to provide uniform bit loading (UBL) for faster link adaptation. Signal to noise ratios (SNRs) for subcarriers of the multicarrier communication channel may be calculated from channel state information and a transmit power level. A throughput may be estimated for the data rates from the SNRs and one of the data rates may be selected based on the estimated throughputs.

GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

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SYSTEM AND METHOD FOR SELECTING DATA RATES TO PROVIDE UNIFORM BIT LOADING OF SUBCARRIERS OF A MULTICARRIER COMMUNICATION CHANNEL

<u>Cross-Reference to Related Applications</u>

5   This application claims the benefit of priority to U.S. Provisional Patent Application Serial No. 60/536,071, filed January 12, 2004, and U.S. Patent Application Serial No. 10/815,035 filed March 30, 2004, which are incorporated herein by reference.

10   <u>Technical Field</u>

Embodiments of the present invention pertain to electronic communication, and in some embodiments, to wireless networks using orthogonal frequency division multiplexed (OFDM) communication signals.

<u>Background</u>

15   Communication stations desirably adapt their communications to changing channel conditions to improve communications in a wireless network. One problem with some conventional communication stations is that a significant amount of feedback between a receiving station and a transmitting station is generally required to optimize channel throughput. This feedback

20   consumes channel bandwidth and requires significant processing by the communication station. Thus there are general needs for communication stations and methods for adapting to channel conditions with less feedback.

<u>Brief Description of the Drawings</u>

The appended claims are directed to some of the various embodiments of

25   the present invention. However, the detailed description presents a more complete understanding of embodiments of the present invention when considered in connection with the figures, wherein like reference numbers refer to similar items throughout the figures and:

FIG. 1 is a block diagram of a communication station in accordance with

30   some embodiments of the present invention;

FIG. 2 is a data rate table in accordance with some embodiments of the present invention; and

FIG. 3 is a flow chart of a data rate selection procedure in accordance with some embodiments of the present invention.

5   Detailed Description

The following description and the drawings illustrate specific embodiments of the invention sufficiently to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Examples merely typify possible variations.

10   Individual components and functions are optional unless explicitly required, and the sequence of operations may vary. Portions and features of some embodiments may be included in or substituted for those of others. The scope of embodiments of the invention encompasses the full ambit of the claims and all available equivalents of those claims. Such embodiments of the invention may

15   be referred to, individually or collectively, herein by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed.

FIG. 1 is a block diagram of a communication station in accordance with

20   some embodiments of the present invention. Communication station 100 may be a wireless communication device and may transmit and/or receive wireless communications signals with transmitter circuitry 102 and/or receiver circuitry 104 using one or more antennas 106. In some embodiments, communication station may communicate multicarrier signals, such as orthogonal frequency

25   division multiplexed (e.g., OFDM) communication signals, with one or more other communication stations as described in more detail below.

In some embodiments, communication station 100 may be referred to as a receiving station, and in some embodiments, communication station 100 may be referred to as a transmitting station. The term transmitting station refers to the

30   station that is to transmit payload data, while the term receiving station refers to

the station that is to receive the payload data. In general, both transmitting and receiving stations may transmit and receive packets.

In accordance with embodiments of the present invention, communication station 100 may select a data rate for communications with another communication station to provide uniform bit loading (UBL) for faster link adaptation. In these embodiments, channel state information (CSI) processing circuitry 108 calculate momentary signal to noise ratios (SNRs) for subcarriers of a multicarrier communication channel from a transmit power level and channel state information. Data rate selection circuitry 110 may estimate a throughput for each of several possible data rates from the SNRs and may select one of the data rates based on the estimated throughputs. In some embodiments, data rate selection circuitry 110 may select one of the data rates based on the estimated throughputs and predicted packet error ratios (PERs), discussed in more detail below.

In some embodiments, data rate selection circuitry 110 may select one of the data rates from a combination of modulations and code rates associated with a highest of the estimated throughputs for a target PER, although the scope of the present invention is not limited in this respect.

In some embodiments, data rate selection circuitry 110 may predict PERs from the SNRs for each of the possible data rates and may estimate the throughput for each data rate from the predicted PERs. In some embodiments, data rate selection circuitry 110 may predict PERs using SNR performance curves for the data rates to determine a PER for each data rate. The SNR performance curves may be predetermined and stored in a memory of communication station 100, although the scope of the present invention is not limited in this respect.

In some embodiments, data rate selection circuitry 110 may calculate a bit-error rate (BER), based on a known modulation of the current packet. In some of these embodiments, data rate selection circuitry 110 may determine a PER for each of the data rates based on a predetermined (i.e., a known) BER performance of the decoder used by the receiver circuitry 104, the calculated

BER, and/or a length of the current packet. In some other of these embodiments, data rate selection circuitry 110 may determine a PER for each of the data rates based on a predetermined symbol error rate (SER), the calculated BER and a length of the current packet. The SER may be based on performance curves,

5   although the scope of the invention is not limited in this respect. .

In some embodiments, data rate selection circuitry 110 may estimate a throughput for each possible data rate by multiplying an associated one of the data rates by one minus the PER predicted for that data rate. This is described in more detail below.

10   In some embodiments, data rate selection circuitry 110 may select one of the data rates from a target PER using estimates of a mean and variance (M/V) adaptation of subcarrier SNRs for the current channel realization. In these embodiments, fast link adaptation is based on estimates of the mean and variance of subcarrier gains. In some embodiments, the M/V adaptation may be performed

15   by calculating a mean channel power gain for each channel realization, calculating a variance of the normalized channel realization, and calculating suitable SNRs for supported data rates. In these embodiments, the M/V adaptation may also include comparing a current SNR averaged over the subcarriers for the current channel realization with predicted SNRs and choosing

20   a suitable data rate. In these embodiments, the use of mean and variance (M/V) adaptation takes into account the variance of a frequency-selective channel, allowing a given PER system performance to be obtained for different channel realizations. In some embodiments, selecting the data rate may depend on the link adaptation strategy (e.g. throughput maximization or throughput

25   maximization under PER constraints).

In some embodiments, the mean channel power gain (M) may be calculated using the following equation:

$$M = \frac{1}{N_{sc}} \sum_{k=1}^{N_{sc}} \lambda(k)$$

In this equation, N_{sc} is number of data subcarriers, k is a subcarrier index

30   of the data subcarriers, and λ refers to the particular subcarrier.

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In some embodiments, the variance of the normalized channel realization (K) may be calculated using the following equation:

$$K = \frac{1}{M(N_{sc}-1)} \sum_{k=1}^{N_{sc}} \left(\sqrt{\lambda(k)} - \frac{1}{N_{sc}} \sum_{j=1}^{N_{sc}} \sqrt{\lambda(j)} \right)^2$$

In this equation, N_{sc} is number of data subcarriers, k is a subcarrier index

5   of the data subcarriers, and λ refers to the particular subcarrier.

In some embodiments, suitable SNRs may be calculated for supported data rates may be calculated using the following equation:

$$SNR_i^{predicted} = f_i(K)$$

In this equation, i refers to the data rate index, and $f_i(x)$ – is a function

10 describing the dependence between channel variance and desired SNR.

FIG. 2 is a data rate table in accordance with some embodiments of the present invention. Column 202 of table 200 lists examples of possible data rates (in bits per second), column 204 lists modulation types and column 206 lists

15 forward error correction (FEC) code rates. For any particular row, the data rate of column 202 may correspond with the associated modulation and code rate of columns 204 and 206 respectively. In some embodiments, data rate selection circuitry 110 (FIG. 1) may use the following expression to estimate a throughput for each possible data rate based on the predicted PER value for each data rate:

20

$$Throughput_i \approx RATE_i *(1-PER_i),$$

In this expression, i represents an index of the data rate, examples of which are listed in column 208. In some embodiments, more or fewer data rates

25 than those illustrated in table 200 with indices in column 308 may be assigned an index and throughputs may be calculated. The data rates that are assigned indices are examples of possible data rates selected that may be used in calculating throughput. In some embodiments, other data rates may be assigned indices, and there is no requirement that only 8 indices are used.

Referring back to FIG. 1, in some embodiments, data rate selection circuitry 110 may generate a data rate instruction for use by transmitter circuitry of another communication station. The data rate instruction may include the selected modulation and code rate.

5   In some embodiments, channel state information processing circuitry 108 and data rate selection circuitry 110 may perform the operations discussed herein as part of a receiving station (e.g., communication station 100). In these embodiments, channel state information processing circuitry 108 may calculate the subcarrier SNRs for a transmit power level provided by a transmitting station

10   (e.g., a station other than communication station 100) in a current packet. In other embodiments, channel state information processing circuitry 108 may calculate the subcarrier SNRs for other available transmit power levels which may be supported by a transmitting station in the next packets. The current packet may be a request to send (RTS) packet, although the scope of the present

15   invention is not limited in this respect. In these embodiments, channel state information processing circuitry 108 may determine the channel state information from channel estimates and noise power estimates performed on the RTS packet. Data rate selection circuitry 110 may estimate throughputs, select the data rate and generate a data rate and transmit power level instructions for a

20   next packet. In these embodiments, transmitter circuitry 102 may be used to send the data rate instructions to the transmitting station in another packet, such as a clear-to-send (CTS) packet. In response to the CTS packet, the transmitting station may transmit at least portions of a data packet (e.g., a packet having a data portion) to communication station 100 in accordance with the data rate and

25   transmit power level instructions.

In some other embodiments, channel state information processing circuitry 108 and data rate selection circuitry 110 may perform the operations discussed herein as part of a transmitting station. In these embodiments, a receiving station (e.g., a station other than communication station 100) may

30   provide the transmitting station (e.g., communication station 100) with channel state information in feedback packet, for example. In these embodiments,

channel state information processing circuitry 108 may calculate the subcarrier SNRs based on a transmit power level (known by the transmitting station) and the provided channel state information. Data rate selection circuitry 110 may estimate throughputs, select the data rate and generate a data rate instruction. In

5   these embodiments, transmitter circuitry 102 of communication station 100 may transmit at least portions of a data packet (e.g., a packet having a data portion) to the receiving station in accordance with the data rate instruction determined therein.

     In some embodiments, communication station 100 may communicate

10   with one or more other communication stations over a multicarrier communication channel, such as an OFDM communication channel. The multicarrier communication channel may be a slowly varying frequency selective channel, although the scope of the invention is not limited in this respect. The multicarrier channel may comprise one or more subchannels. The subchannels

15   may be frequency-division multiplexed (i.e., separated in frequency) and may be within a predetermined frequency spectrum. The subchannels may comprise a plurality of orthogonal subcarriers. In some embodiments, the orthogonal subcarriers of a subchannel may be closely spaced OFDM subcarriers. To achieve orthogonality between closely spaced subcarriers, in some embodiments,

20   the subcarriers of a particular subchannel may have a null at substantially a center frequency of the other subcarriers of that subchannel. In some embodiments, the subcarriers of a subchannel may have a spacing therebetween of between 300 and 400 kHz, although the scope of the invention is not limited in this respect.

25   In some embodiments, the multicarrier communication channel may comprise either a standard-throughput channel or a high-throughput communication channel. In these embodiments, the standard-throughput channel may comprise one subchannel and the high-throughput channel may comprise a combination of one or more subchannels and one or more spatial channels

30   associated with each subchannel. Spatial channels are non-orthogonal channels (in terms of frequency) associated with a particular subchannel. In these

embodiments, CSI processing circuitry 108 may calculate momentary SNRs for each subcarrier of the one or more subchannels and the one or more spatial channels comprising the multicarrier communication channel from the current and/or available transmit power level and the channel state information. In these

5   embodiments, the data rate and transmit power level instructions may include a selected modulation type, a selected code rate and a transmit power allocation for each of the one or more subchannels and/or each of the one or more spatial channels comprising the multicarrier communication channel. In these embodiments, channel state information processing circuitry 110 may determine

10   the channel state information including noise power estimates and a channel transfer function for each subcarrier of the one or more spatial channels and the one or more subchannels. The channel transfer function may define the frequency and/or time characteristics of the channel.

In some embodiments, a high-throughput communication channel may

15   comprise a wideband channel having up to four frequency separated subchannels, a multiple-input-multiple-output (MIMO) channel comprising a single subchannel having up to four spatial subchannels, or a wideband-MIMO channel comprising two or more frequency separated subchannels where each subchannel has two or more spatial channels. In these embodiments, a wideband

20   channel may have a wideband channel bandwidth of up to 80 MHz and may comprise up to four of the subchannels, although the scope of the invention is not limited in this respect. The subchannels may have a subchannel bandwidth of approximately 20 MHz, although the scope of the invention is not limited in this respect.

25   In some embodiments, communication station 100 may comprise more than one of antennas 106 to communicate over more than one spatial channel within a subchannel. In these embodiments, the multicarrier communication channel may be a high-throughput communication channel.

In some embodiments, receiver circuitry 104 may comprise a plurality of

30   subcarrier demodulators to demodulate the subcarriers of the multicarrier channel that were modulated in accordance with modulations comprising at least

8

some of binary phase shift keying (BPSK), quadrature phase shift keying
(QPSK), 8PSK, 16-quadrature amplitude modulation (16-QAM), 32-QAM, 64-
QAM, 128-QAM, and 256-QAM. In these embodiments, receiver circuitry 104
may also include decoding circuitry, such as a convolutional decoder to decode

5   bit streams encoded with forward error correction (FEC) code rates of ½, 2/3,
and ¾, although the scope of the invention is not limited in this respect.

In some embodiments, data rate selection circuitry 110 may select various
data rates (i.e., bit distributions) comprising various modulations and code rates
for each of the subcarriers of the multicarrier communication channel based on

10   the SNR for the associated subcarrier. In some embodiments, the bit distributions
may be based on a bit loading per subcarrier in accordance with an adaptive bit
loading (ABL) technique in which a modulation may be selected for each
subcarrier based on the channel conditions of that subcarrier. In these
embodiments, data rate selection circuitry 110 may calculate throughput estimate

15   for each of the one or more spatial channels and/or each of the one or more
subchannels for the multicarrier communication channel. Data rate selection
circuitry 110 may further select a data rate for all data subcarriers of each of the
one or more spatial channels and/or each of the one or more subchannels of the
multicarrier communication channel based on the calculated throughput

20   estimates.

In some embodiments, data rate selection circuitry 110 may determine an
upper and a lower data rate based on the sum of the subcarrier throughputs (the
sum of the bits distributed over subcarriers). In some embodiments, data rate
selection circuitry 110 may determine the possible data rates just above and just

25   below the sum of the subcarrier throughputs. In some embodiments, data rate
selection circuitry 110 may calculate a first number of subcarriers with
throughputs higher than the upper data rate, and may calculate a second number
of subcarriers with throughputs lower than the lower data rate. Data rate
selection circuitry 110 may then select the upper data rate when a difference

30   between the first and second numbers is greater than a predetermined percentage
(e.g., 25%) of the subcarriers comprising the multicarrier communication

channel. The lower data rate may be selected when the difference between the first and second numbers is not greater than the predetermined percentage of the subcarriers. In some embodiments, the predetermined percentage may range between 0% and 60%, although the scope of the invention is not limited in this

5   respect.

In some other embodiments, data rate selection circuitry 110 may calculate a subcarrier capacity for each possible data rate based on the SNR calculated for each subcarrier of the multicarrier communication channel. Data rate selection circuitry 110 may refrain from estimating the throughput for each

10   of the data rates, and may select one of the possible data rates of the plurality based on a sum of the subcarrier capacities. In some embodiments, data rate selection circuitry 110 may select a possible data rate closest to the sum of the subcarrier capacities. In these embodiments, data rate selection circuitry 110 may calculate the subcarrier capacity for each subcarrier substantially by multiplying

15   a subcarrier frequency spacing (ΔF) by a logarithm of one plus the SNR for the associated subcarrier divided by a predetermined subcarrier SNR gap (Γ). The predetermined subcarrier SNR gap (Γ) may represent a predetermined SNR gap or SNR margin representing how far a practical communication station may be from achieving a theoretical capacity, although the scope of the present invention

20   is not limited in this respect. In some embodiments, the subcarrier capacity of each of the subcarrier may be calculated substantially from the following expression:

$$\text{Subcarrier Capacity}_i = \Delta F * \log_2(1+\text{SNR}_i/\Gamma)$$

25

In this expression, i represents a subcarrier index, ΔF represents a subcarrier frequency spacing, and SNRi represents the SNR of the ith subcarrier.

In some embodiments, data rate selection circuitry 110 may determine an upper and a lower data rate based on the sum of the subcarrier capabilities. In

30   some embodiments, data rate selection circuitry 110 may determine the possible data rates (i.e., from column 202 of table 200) just above and just below the sum

of the subcarrier capacities. In some embodiments, data rate selection circuitry 110 may calculate a first number of subcarriers with capacities higher than the upper data rate, and may calculate a second number of subcarriers with capacities lower than the lower data rate. Data rate selection circuitry 110 may then select

5   the upper data rate when a difference between the first and second numbers is greater than a predetermined percentage (e.g., 25%) of the subcarriers comprising the multicarrier communication channel. The lower data rate may be selected when the difference between the first and second numbers is not greater than the predetermined percentage of the subcarriers. In some embodiments, the

10   predetermined percentage may range between 20% and 60%, although the scope of the invention is not limited in this respect.

In some embodiments, each of the subchannels may have up to 48 or more orthogonal data subcarriers, and the subcarriers may have a spacing therebetween of approximately 312.5 kHz, although the scope of the invention is

15   not limited in this respect. In some embodiments, the frequency spectrums for a multicarrier communication channel may comprise subchannels in either a 5 GHz frequency spectrum or a 2.4 GHz frequency spectrum. In these embodiments, the 5 GHz frequency spectrum may include frequencies ranging from approximately 4.9 to 5.9 GHz, and the 2.4 GHz spectrum may include

20   frequencies ranging from approximately 2.3 to 2.5 GHz, although the scope of the invention is not limited in this respect, as other frequency spectrums are also equally suitable.

Communication station 100 may be a personal digital assistant (PDA), a laptop or portable computer with wireless-networking communication capability,

25   a web tablet, a wireless telephone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point or other device that may receive and/or transmit information wirelessly. In some embodiments, communication station 100 may transmit and/or receive radio-frequency (RF) communications in accordance with specific communication standards, such as

30   the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11(a), 802.11(b), 802.11(g/h), 802.11(n) and/or 802.16 standards for

wireless local area networks, although in other embodiments, communication station 100 may also be suitable to transmit and/or receive communications in accordance with other techniques including the Digital Video Broadcasting Terrestrial (DVB-T) broadcasting standard, and the High performance radio

5   Local Area Network (HiperLAN) standard.

Antennas 106 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, loop antennas, microstrip antennas, patch antennas, slot antennas or other type of antennas suitable for reception and/or transmission of the signals within the

10   spectrum communication channel.

As used herein, channel state information may comprise one or more of a channel transfer function, or estimate thereof, one or more RF signal characteristics, and/or one or more channel quality parameters. In some embodiments, channel state information may include a channel transfer function

15   estimate in the frequency or time domain. In some embodiments, channel state information may include one or more RF channel performance indicators such as SNR, signal-to-interference and noise ratio (SINR), a received signal strength indication (RSSI), and the like. In some embodiments, channel state information may also include one or more channel quality parameters associated with

20   information decoded from a received signal.

Although communication station 100 is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors

25   (DSPs), and/or other hardware elements. For example, the circuitry illustrated may comprise processing elements which may comprise one or more microprocessors, DSPs, application specific integrated circuits (ASICs), and combinations of various hardware and logic circuitry for performing at least the functions described herein.

30   FIG. 3 is a flow chart of a data rate selection procedure in accordance with some embodiments of the present invention. Data rate selection procedure

300 may be performed by a communication station, such as communication station 100 (FIG. 1), although other communication stations may also be suitable for performing procedure 300. In some embodiments, data rate selection procedure 300 may select a data rate for subcarriers a subchannel comprising of a

5   standard-throughput channel. In other embodiments, data rate selection procedure 300 may select a data rate for subcarriers each subchannel and/or each spatial channel comprising of a high-throughput channel. The data rates selected by procedure 300 may provide a uniform bit loading for faster link adaptation. In some embodiments, procedure 300 may be performed by a receiving station to

10   generate data rate and transmit power level instructions for use by a transmitting station in transmitting a subsequent packet to the receiving station. In some other embodiments, procedure 300 may be performed by a transmitting station for use in transmitting a subsequent packet to a receiving station.

Operation 302 comprises receiving channel state information. In some

15   embodiments, the channel state information may be generated by a receiving station from channel estimates 304, noise power estimated 306 and a transmit power level 308. In some embodiments, transmit power levels may be provided to the receiving station in a current packet sent by the transmitting station. In some embodiments, when procedure 300 is performed by a transmitting station,

20   operation 302 may further comprise the receiving station sending the transmitting station the channel state information in a feedback packet. In some embodiments, the channel state information generated in operation 302 may be generated by channel state information processing circuitry 108 (FIG. 1) of a receiving station, although the scope of the invention is not limited in this

25   respect.

Operation 310 comprises calculating momentary signal to noise ratios (SNRs) for subcarriers of the multicarrier communication channel from the transmit power level and the channel state information from operation 302. In some embodiments, operation 310 may be performed by data rate selection

30   circuitry 110 (FIG. 1), although the scope of the invention is not limited in this respect.

In some embodiments, operation 312 is performed. Operation 312 comprises predicting packet error ratios (PERs) from the SNRs for each of the data rates. In some embodiments, operation 312 comprises using SNR performance curves 314 for the data rates to determine a PER for each data rate.

5   The SNR performance curves may be predetermined and may be stored in a memory of the communication station. In some other embodiments, operation 312 may comprise after demapping bits of a current packet, calculating bit-error rates (BERs) 316 based on a known modulation of the current packet (e.g., an RTS packet), and after decoding the bits of the current packet, determining a

10   PER for each data rate based on a predetermined BER performance of a decoder, the calculated BER, and a length of the current packet. In some embodiments, operation 312 may be performed by data rate selection circuitry 110 (FIG. 1), although the scope of the invention is not limited in this respect.

        Operation 318 comprises estimating a throughput for each of a plurality

15   of data rates from the SNRs. In some embodiments, operation 318 may comprise estimating the throughput for each data rate by multiplying an associated one of the data rates by one minus the PER predicted for the associated data rate. In some embodiments, operation 318 may be performed by data rate selection circuitry 110 (FIG. 1), although the scope of the invention is not limited in this

20   respect.

        Operation 322 comprises selecting one of the data rates based on the estimated throughputs. In some embodiments, operation 322 may comprise selecting a combination modulations and code rates determined to provide a highest of the estimated throughputs. Examples of modulations and code rates

25   associated with data rates are illustrated in table 200 (FIG. 2). When operation 312 is performed, operation 322 may comprise estimating a throughput for each of the data rates from the predicted PERs.

        Operation 324 comprises generating data rate and transmit power level instructions for a transmitting station. The data rate instruction may include the

30   selected modulation type and code rate. In some embodiments, operation 324

may be performed by data rate selection circuitry 110 (FIG. 1), although the scope of the invention is not limited in this respect.

In some embodiments, operation 302 may be performed by a receiving station based on a known transmit power level provided by the transmitting

5   station in a current packet. The known transmit power level refers to the transmit power level of the current packet as well as available transmit power levels that the transmitting station may use. The current packet may be a request to send (RTS) packet. In these embodiments, the receiving station may determine the channel state information from channel estimates and noise power estimates

10   performed on the RTS packet. After operation 324, the receiving station may send the data rate and transmit power level instructions to a transmitting station in a clear-to-sent (CTS) packet, and the transmitting station to responsively transmit at least portions of a data packet to the receiving station in accordance with the data rate instruction.

15   In some embodiments, the multicarrier communication channel may comprise either a standard-throughput channel or a high-throughput communication channel. In these embodiments, the standard-throughput channel may comprise one subchannel and the high-throughput channel may comprising a combination of one or more subchannels and/or one or more spatial channels

20   associated with each subchannel. In these embodiments, operation 310 may comprise calculating momentary SNRs for each subcarrier of the one or more subchannels and/or the one or more spatial channels comprising the multicarrier communication channel from the transmit power level and the channel state information. In these embodiments, operation 324 may comprise generating a

25   data rate instruction to include a selected modulation type, a selected code rate and transmit power allocation for each of the one or more subchannels and/or each of the one or more spatial channels comprising the multicarrier communication channel. In these embodiments, operation 302 may comprise determining the channel state information including noise power estimates and a

30   channel transfer function for each subcarrier of the one or more spatial channels and/or the one or more subchannels of the multicarrier communication channel.

In some embodiments, transmit power may be allocated to subchannels and/or spatial channels of a high-throughput multicarrier communication channel in accordance with a power allocation algorithm. The power allocation algorithm may use SNR, PER, BER and/or other capabilities of the subchannels and/or

5   spatial channels to allocate transmit power to the subcarriers.

In some other embodiments, operation 318 may comprise selecting various data rates (bit distributions) comprising various modulations and code rates for each of the subcarriers of the multicarrier communication channel based on the SNR for the associated subcarrier and calculating throughputs for each of

10   the one or more spatial channels and/or each of the one or more subchannels of the multicarrier communication channel. In these other embodiments, operation 322 may comprise selecting a data rate for the subcarriers of each of the one or more spatial channels and/or each of the one or more subchannels of the multicarrier communication channel.

15   In accordance with other embodiments, operation 310 may further comprise calculating a subcarrier capacity for each of the data rates based on the SNR calculated in operation 310 for an associated one of the subcarriers. In these embodiments, operations 322 may comprise selecting one of the data rates based on a sum of the subcarrier capacities. In these embodiments, the subcarrier

20   capacity for each subcarrier may be calculated by multiplying a subcarrier frequency spacing (ΔF) by a logarithm of one plus the SNR for the associated subcarrier divided by a predetermined subcarrier SNR gap (Γ). In these embodiments, operation 322 may comprise determining an upper and a lower data rate based on the sum of the subcarrier capabilities, calculating a first

25   number of subcarriers with capacities higher than the upper data rate, and calculating a second number of subcarriers with capacities lower than the lower data rate. In these embodiments, operation 322 may also comprise selecting the upper data rate when a difference between the first and second numbers is greater than a predetermined percentage of the subcarriers comprising the multicarrier

30   communication channel. Otherwise, the lower data rate may be selected.

Although the individual operations of procedure 300 are illustrated and
described as separate operations, one or more of the individual operations may
be performed concurrently, and nothing requires that the operations be performed
in the order illustrated. Unless specifically stated otherwise, terms such as

5   processing, computing, calculating, determining, displaying, or the like, may
refer to an action and/or process of one or more processing or computing systems
or similar devices that may manipulate and transform data represented as
physical (e.g., electronic) quantities within a processing system's registers and
memory into other data similarly represented as physical quantities within the

10   processing system's registers or memories, or other such information storage,
transmission or display devices.

Some embodiments of the present invention may be implemented in one
or a combination of hardware, firmware and software. Embodiments of the
invention may also be implemented as instructions stored on a machine-readable

15   medium, which may be read and executed by at least one processor to perform
the operations described herein. A machine-readable medium may include any
mechanism for storing or transmitting information in a form readable by a
machine (e.g., a computer). For example, a machine-readable medium may
include read-only memory (ROM), random-access memory (RAM), magnetic

20   disk storage media, optical storage media, flash-memory devices, electrical,
optical, acoustical or other form of propagated signals (e.g., carrier waves,
infrared signals, digital signals, etc.), and others.

The Abstract is provided to comply with 37 C.F.R. Section 1.72(b)
requiring an abstract that will allow the reader to ascertain the nature and gist of

25   the technical disclosure. It is submitted with the understanding that it will not be
used to limit or interpret the scope or meaning of the claims.

In the foregoing detailed description, various features are occasionally
grouped together in a single embodiment for the purpose of streamlining the
disclosure. This method of disclosure is not to be interpreted as reflecting an

30   intention that the claimed embodiments of the subject matter require more
features than are expressly recited in each claim. Rather, as the following claims

reflect, invention lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate preferred embodiment.

CLAIMS

What is claimed is:

1. A method of selecting a data rate of a multicarrier communication
5   channel, the method comprising:

calculating signal to noise ratios (SNRs) for subcarriers of the
multicarrier communication channel from channel state information and a
transmit power level;

estimating a throughput for each of a plurality of data rates from the
10   SNRs; and

selecting one of the data rates based on the estimated throughputs.

2. The method of claim 1 wherein selecting one of the data rates
comprises selecting a combination of one of a plurality of modulations and one a
plurality of code rates associated with a highest of the estimated throughputs.

15   3. The method of claim 2 further comprising predicting packet error
ratios (PERs) from the SNRs for each of the data rates, and

wherein the estimating the throughput comprises estimating a throughput
for each of the data rates from the predicted PERs.

4. The method of claim 3 wherein predicting the PERs comprises using
20   SNR performance curves for the plurality of data rates to determine a PER for
each data rate, the SNR performance curves being predetermined and stored in a
memory of a receiving station.

5. The method of claim 3 wherein the predicting PERs comprises:

after demapping bits of a current packet, calculating a bit-error rate
25   (BER), based on a modulation of the current packet; and

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after decoding the bits of the current packet, determining a PER for each of the plurality of data rates based on a predetermined BER performance of a decoder, the calculated BER, and a length of the current packet.

6. The method of claim 3 wherein the estimating the throughput comprises estimating a throughput for each data rate of the plurality by multiplying an associated one of the data rates by one minus the PER predicted for the associated data rate.

7. The method of claim 2 further comprising generating transmit power level and data rate instructions for a transmitting station, the transmit power level and data rate instructions to include the selected modulation and code rate and a selected transmit power level.

8. The method of claim 7 wherein the calculating operation is performed by a receiving station based on a known transmit power level provided by the transmitting station in a current packet, the current packet being a request to send (RTS) packet,

wherein the method further comprises:

determining, by the receiving station, the channel state information from channel estimates and noise power estimates performed on the RTS packet; and

sending, by the receiving station, the data rate instruction to the transmitting station in a clear-to-sent (CTS) packet, the transmitting station to responsively transmit at least portions of a data packet to the receiving station in accordance with the data rate instruction.

9. The method of claim 1 wherein the multicarrier communication channel comprises either a standard-throughput channel or a high-throughput communication channel, the standard-throughput channel comprising one subchannel, the high-throughput channel comprising a combination of one or

more subchannels and one or more spatial channels associated with each
subchannel, and

  wherein calculating the SNRs comprises calculating SNRs for each
subcarrier of the one or more subchannels and the one or more spatial channels

5 comprising the multicarrier communication channel from the transmit power
level and the channel state information, and

  wherein the method further comprises generating a data rate instruction
for a transmitter, the data rate instruction to include a selected modulation and a
selected code rate for the one or more subchannels and the one or more spatial

10 channels comprising the multicarrier communication channel.

  10. The method of claim 9 further comprising determining the channel
state information, the channel state information including noise power estimates
and a channel transfer function for each subcarrier of the one or more spatial
channels and the one or more subchannels.

15 11. The method of claim 9 wherein the high-throughput communication
channel comprises one of:

  a wideband channel having up to four frequency separated subchannels;

  a multiple-input-multiple-output (MIMO) channel comprising a single
subchannel having up to four spatial subchannels; and

20 a wideband-MIMO channel comprising two or more frequency separated
subchannels, each subchannel having two or more spatial channels.

  12. The method of claim 11 wherein the wideband channel has a
wideband channel bandwidth of up to 80 MHz and comprises up to four of the
subchannels,

25 wherein the subchannels are non-overlapping orthogonal frequency
division multiplexed channels,

  wherein each subchannel has a subchannel bandwidth of approximately
20 MHz and comprises a plurality of orthogonal subcarriers, and

wherein the one or more spatial channels are non-orthogonal channels associated with one of the subchannels.

13. The method of claim 9 wherein when the multicarrier communication channel is a high-throughput communication channel, the one or more spatial

5   channels and the one or more subchannels are provided by a corresponding one or more transmit antennas of a transmitting station.

14. The method of claim 9 wherein the subcarriers of an associated subchannel have a null at substantially a center frequency of the other subcarriers to achieve substantial orthogonality between the subcarriers of the associated

10   subchannel.

15. The method of claim 2 wherein the plurality of modulations comprise binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 8PSK, 16-quadrature amplitude modulation (16-QAM), 32-QAM, 64-QAM, 128-QAM, and 256-QAM, and

15   wherein the plurality of code rates comprise forward error correction (FEC) code rates of ½, 2/3, and ¾.

16. The method of claim 1 wherein the data rate is further selected based on a mean-variance adaptation that includes a mean channel power gain based on channel gains for each of the subcarriers, a variance of the mean channel power

20   gain, and predicted SNRs for each of the data rates.

17. The method of claim 1 wherein estimating the throughput comprises selecting various data rates for each of the subcarriers of the multicarrier communication channel based on the SNR for the associated subcarrier, and
      wherein estimating the throughput comprises calculating throughputs for

25   the multicarrier communication channel for the various data rates,

wherein selecting comprises selecting a single data rate for the
subcarriers of one or more spatial channels and one or more subchannels of the
multicarrier communication channel.

18. The method of claim 1 further comprising:

5   after calculating the SNRs for each subcarrier of the multicarrier
communication channel, calculating a subcarrier capacity for each of the data
rates based on the SNR calculated for an associated one of the subcarriers; and
          refraining from estimating the throughput for each of the data rates, and
          wherein selecting the data rate comprises selecting one of the data rates

10   of the plurality based on a sum of the subcarrier capacities.

19. The method of claim 18 wherein the subcarrier capacity for each
subcarrier is substantially calculated by multiplying a subcarrier frequency
spacing by a logarithm of one plus the SNR for the associated subcarrier divided
by a predetermined subcarrier SNR gap.

15   20. The method of claim 18 wherein selecting the data rate comprises:
          determining an upper and a lower data rate based on the sum of the
subcarrier capabilities;
          calculating a first number of subcarriers with capacities higher than the
upper data rate;

20   calculating a second number of subcarriers with capacities lower than the
lower data rate; and
          selecting the upper data rate when a difference between the first and
second numbers is greater than a predetermined percentage of the subcarriers
comprising the multicarrier communication channel.

21. A communication station comprising:

channel state information processing circuitry to calculate signal to noise ratios (SNRs) for subcarriers of the multicarrier communication channel from a transmit power level and channel state information; and

5   data rate selection circuitry to estimate a throughput for each of a plurality of data rates from the SNRs,

wherein the data rate selection circuitry selects one of the data rates based on the estimated throughputs.

22. The communication station of claim 21 wherein the data rate

10   selection circuitry selects one of the data rates from a combination of one of a plurality of modulations and one a plurality of code rates associated with a highest of the estimated throughputs.

23. The communication station of claim 22 wherein the data rate selection circuitry further predicts packet error ratios (PERs) from the SNRs for

15   each of the data rates and estimates the throughput comprises estimating a throughput for each of the data rates from the predicted PERs.

24. The communication station of claim 23 wherein the data rate selection circuitry predicts PERs comprises using SNR performance curves for the plurality of data rates to determine a PER for each data rate, the SNR

20   performance curves being predetermined and stored in a memory of a receiving station.

25. The communication station of claim 23 wherein the data rate selection circuitry calculates a bit-error rate (BER), based on a known modulation of the current packet, and determines a PER for each of the plurality

25   of data rates based on a predetermined BER performance of a decoder, the calculated BER, and a length of the current packet.

26. The communication station of claim 23 wherein the data rate selection circuitry estimates a throughput for each data rate of the plurality by multiplying an associated one of the data rates by one minus the PER predicted for the associated data rate.

5   27. The communication station of claim 22 wherein the data rate selection circuitry generates transmit power level and data rate instructions for a transmitting station, the transmit power level and data rate instructions to include the selected modulation and code rate and a selected transmit power level.

           28. The communication station of claim 27 wherein the channel state
10   information processing circuitry and the data rate selection circuitry are part of a receiving station, and wherein the data rate selection circuitry calculates the SNRs based on a known transmit power level provided by the transmitting station in a current packet, the current packet being a request to send (RTS) packet,
15   wherein the channel state information processing circuitry determines the channel state information from channel estimates and noise power estimates performed on the RTS packet, and
                wherein transmitter circuitry of the receiving station sends the data rate instruction to the transmitting station in a clear-to-sent (CTS) packet, the
20   transmitting station to responsively transmit at least portions of a data packet to the receiving station in accordance with the data rate instruction.

           29. The communication station of claim 21 wherein the multicarrier communication channel comprises either a standard-throughput channel or a high-throughput communication channel, the standard-throughput channel
25   comprising one subchannel, the high-throughput channel comprising a combination of one or more subchannels and one or more spatial channels associated with each subchannel, and

wherein calculating the SNRs comprises calculating SNRs for each

subcarrier of the one or more subchannels and the one or more spatial channels

comprising the multicarrier communication channel from the transmit power

level and the channel state information, and

5   wherein the communication station further comprises generating a data

rate instruction for a transmitter, the data rate instruction to include a selected

modulation and a selected code rate for the one or more subchannels and the one

or more spatial channels comprising the multicarrier communication channel.

30. The communication station of claim 29 where the channel state

10   information processing circuitry further determines the channel state

information, the channel state information including noise power estimates and a

channel transfer function for each subcarrier of the one or more spatial channels

and the one or more subchannels.

31. The communication station of claim 29 wherein the high-throughput

15   communication channel comprises one of a wideband channel having up to four

frequency separated subchannels, a multiple-input-multiple-output (MIMO)

channel comprising a single subchannel having up to four spatial subchannels,

and a wideband-MIMO channel comprising two or more frequency separated

subchannels, each subchannel having two or more spatial channels.

20   32. The communication station of claim 31 wherein the wideband

channel has a bandwidth of up to 80 MHz and comprises up to four of the

subchannels,

wherein the subchannels are orthogonal frequency division multiplexed

channels,

25   wherein each subchannel has a subchannel bandwidth of approximately

20 MHz and comprises a plurality of orthogonal subcarriers, and

wherein the one or more spatial channels are non-orthogonal channels

associated with one of the subchannels.

33. The communication station of claim 29 further comprising one or more antennas to communicate over the one or more spatial channels and the one or more subchannels when the multicarrier communication channel is a high-throughput communication channel.

5   34. The communication station of claim 29 wherein the subcarriers of an associated subchannel have a null at substantially a center frequency of the other subcarriers to achieve substantial orthogonality between the subcarriers of the associated subchannel.

35. The communication station of claim 22 wherein the plurality of

10   modulations comprise binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 8PSK, 16-quadrature amplitude modulation (16-QAM), 32-QAM, 64-QAM, 128-QAM, and 256-QAM, and

wherein the plurality of code rates comprise forward error correction (FEC) code rates of ½, 2/3, and ¾.

15   36. The communication station of claim 21 wherein the data rate selection circuitry further selects the data rate based on a mean-variance adaptation that includes a mean channel power gain based on channel gains for each of the subcarriers, a variance of the mean channel power gain, and predicted SNRs for each of the data rates.

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37. The communication station of claim 21 wherein the data rate selection circuitry selects various data rates for each of the subcarriers of the multicarrier communication channel based on the SNR for the associated subcarrier, and calculates throughputs for the multicarrier communication

25   channel for the various data rates,

the data rate selection circuitry further selects a single data rate for the subcarriers of one or more spatial channels and one or more subchannels of the multicarrier communication channel.

38. The communication station of claim 21 wherein the data rate

5   selection circuitry calculates a subcarrier capacity for each of the data rates based on the SNR calculated for an associated one of the subcarriers for each subcarrier of the multicarrier communication channel,

the data rate selection circuitry refrains from estimating the throughput for each of the data rates, and

10   the data rate selection circuitry selects one of the data rates of the plurality based on a sum of the subcarrier capacities.

39. The communication station of claim 38 wherein the data rate selection circuitry calculates the subcarrier capacity for each subcarrier substantially by multiplying a subcarrier frequency spacing by a logarithm of one

15   plus the SNR for the associated subcarrier divided by a predetermined subcarrier SNR gap.

40. The communication station of claim 38 wherein the data rate selection circuitry:

determines an upper and a lower data rate based on the sum of the

20   subcarrier capabilities;

calculates a first number of subcarriers with capacities higher than the upper data rate;

calculates a second number of subcarriers with capacities lower than the lower data rate; and

25   selects the upper data rate when a difference between the first and second numbers is greater than a predetermined percentage of the subcarriers comprising the multicarrier communication channel.

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41. A system comprising:

a substantially omnidirectional antenna;

a receiver to receive signals through then antenna through a multicarrier communication channel;

5   channel state information processing circuitry to calculate signal to noise ratios (SNRs) for subcarriers of the multicarrier communication channel from a transmit power level and channel state information; and

data rate selection circuitry to estimate a throughput for each of a plurality of data rates from the SNRs and select one of the data rates based on the

10   estimated throughputs.

42. The system of claim 41 wherein the data rate selection circuitry selects one of the data rates from a combination of one of a plurality of modulations and one a plurality of code rates associated with a highest of the estimated throughputs.

15   43. The system of claim 42 wherein the data rate selection circuitry further predicts packet error ratios (PERs) from the SNRs for each of the data rates and estimates the throughput comprises estimating a throughput for each of the data rates from the predicted PERs.

44. A machine-readable medium that provides instructions, which when

20   executed by one or more processors, cause the processors to perform operations comprising:

calculating signal to noise ratios (SNRs) for subcarriers of an orthogonal frequency division multiplexed communication channel from a transmit power level and channel state information;

25   estimating a throughput for each of a plurality of data rates from the SNRs; and

selecting one of the data rates based on the estimated throughputs.

45. The machine-readable medium of claim 44 wherein the instructions, when further executed by one or more of the processors cause the processors to perform operations further comprising selecting one of the data rates based on selecting a combination of one of a plurality of modulations and one a plurality of code rates associated with a highest of the estimated throughputs.

46. The machine-readable medium of claim 45 wherein the instructions, when further executed by one or more of the processors cause the processors to perform operations further comprising predicting packet error ratios (PERs) from the SNRs for each of the data rates, and
        wherein estimating the throughput comprises estimating a throughput for each of the data rates from the predicted PERs.
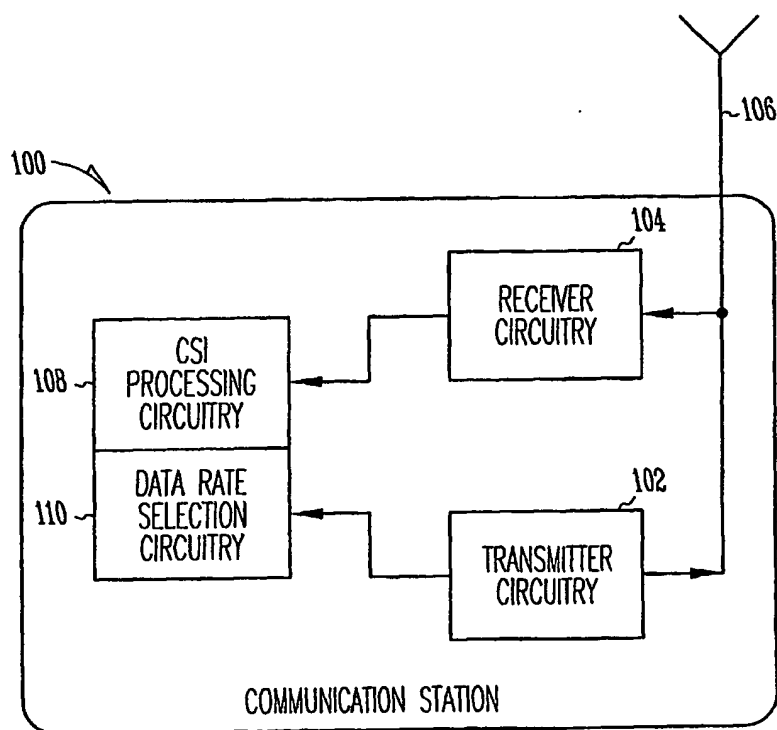
1/3

Fig. 1

200

INDEX	DATA RATE	MODULATION	CODE RATE
208	202	204	206
1	6	BPSK	1/2
--	8	BPSK	2/3
2	9	BPSK	3/4
3	12	QPSK	1/2
--	16	QPSK	2/3
4	18	QPSK	3/4
5	24	16 QAM	1/2
--	32	16 QAM	2/3
6	36	16 QAM	3/4
--	30	32 QAM	1/2
--	40	32 QAM	2/3
--	45	32 QAM	3/4
--	36	64 QAM	1/2
7	48	64 QAM	2/3
8	54	64 QAM	3/4
--	42	128 QAM	1/2
--	56	128 QAM	2/3
--	63	128 QAM	3/4
--	48	256 QAM	1/2
--	64	256 QAM	2/3
--	72	256 QAM	3/4

Fig. 2
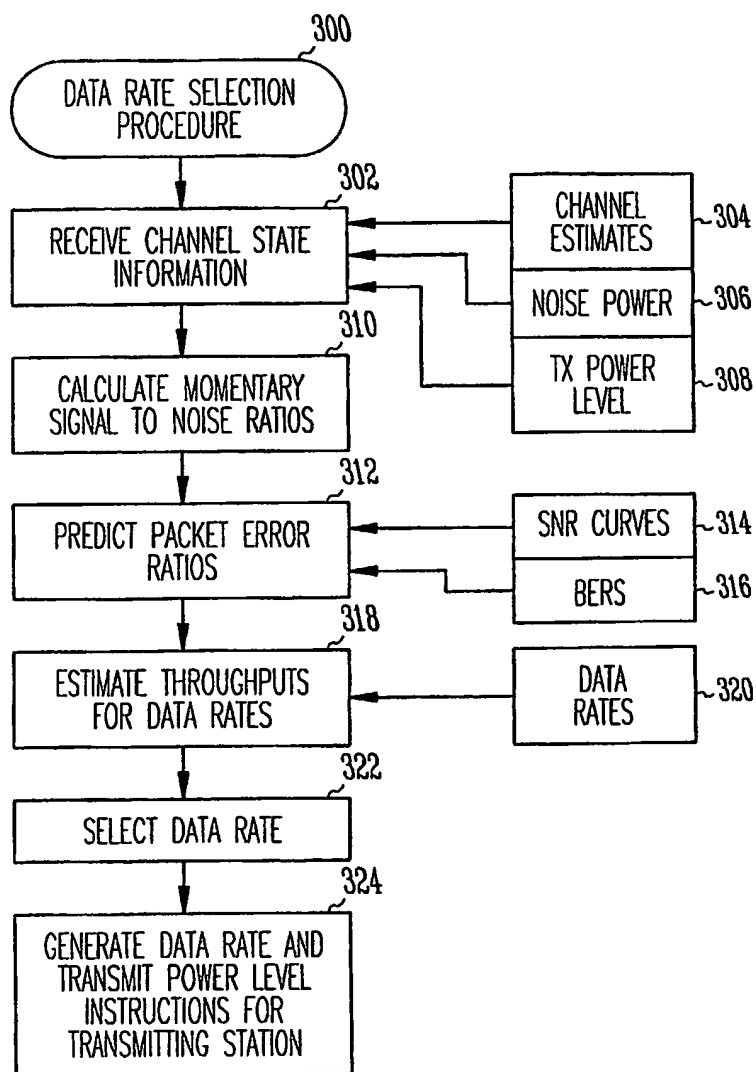
Fig. 3

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04L27/26   H04L1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BANGERTER B ET AL: "High-Throughput Wireless LAN Air Interface" INTEL TECHNOLOGY JOURNAL, US, vol. 7, no. 3, 19 August 2003 (2003-08-19), pages 47-57, XP002324611 page 47, right-hand column, last paragraph "Wideband Adaptive OFDM" on page 50 "MIMO Systems fro High Throughput" on page 48 "Optimized Modulation and Coding Selection" on page 51, right-hand column -/--	1-46

X	Further documents are listed in the continuation of box C.		X	Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 June 2005	06/07/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Horbach, C

Form PCT/ISA/210 (second sheet) (January 2004)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SIMOENS S ET AL: "OPTIMUM PERFORMANCE OF LINK ADAPTATION IN HIPERLAN/2 NETWORKS" VTC 2001 SPRING. IEEE VTS 53RD. VEHICULAR TECHNOLOGY CONFERENCE. RHODES, GREECE, MAY 6 - 9, 2001, IEEE VEHICULAR TECHNOLGY CONFERENCE, NEW YORK, NY : IEEE, US, vol. VOL. 2 OF 4. CONF. 53, 6 May 2001 (2001-05-06), pages 1129-1133, XP001067136 ISBN: 0-7803-6728-6 page 1131, right-hand column - page 1132, left-hand column	1,21,41, 44
A	WO 03/047198 A (QUALCOMM INCORPORATED) 5 June 2003 (2003-06-05) paragraphs '1042! - '1047!	1-46
A	"Supplement to IEEE standard for information technology - telecommunications and information exchange between systems - local and metropolitan area networks - specific requirements. Part 11: wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: high-speed physical layer in" IEEE STD 802.11A-1999, 30 December 1999 (1999-12-30), pages 1-90, XP002189725 page 23, paragraph 3	1-46

INTERNATIONAL SEARCH REPORT

Intern Application No
PCT/US2005/000934

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			US	2003095508 A1	22-05-2003
			AU	2002346470 A1	10-06-2003
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			EP	1454466 A2	08-09-2004
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			WO	03047197 A2	05-06-2003
			WO	03047198 A2	05-06-2003